Shrinkage of backfill gutta-percha upon cooling

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Abstract: INTRODUCTION The temperature and related shrinking kinetics of gutta-percha injected from heat guns are not known; therefore, we investigated them in this study. METHODS The temperatures of 3 different backfill gutta-percha brands extruded from 3 commercially available heat guns set to 200°C were studied. To validate the results, temperature development of 1 gutta-percha brand injected from a heat gun during a simulated backfilling procedure was assessed in single-rooted human teeth containing thermocouples in a water bath of 37°C. These values were compared with the counterparts obtained in a tabletop testing device for shrinkage at an ambient temperature of 37°C. Using this device, linear shrinkage upon cooling was assessed for all 3 gutta-percha brands under investigation. Results were compared by parametric statistics (alpha = .05). RESULTS The temperatures of extruded gutta-percha differed significantly ($P < .05$) between heat guns and gutta-percha brands. Mean temperatures ranging between 57.6° ± 4.5°C and 103.9° ± 7.8°C could be observed with different combinations. The temperature of extruded gutta-percha in tabletop experiments equaled that observed in the root canals. However, the cooling of gutta-percha was ($P < .05$) faster in the tabletop measuring device compared with the root canal environment. Within the controlled temperature drop from 75°C to 37°C, the total shrinkage differed significantly ($P < .05$) between the 3 gutta-percha brands under investigation and ranged between 0.96% ± 0.20% and 2.31% ± 0.26% after 10 minutes ($P < .05$). Shrinking kinetics showed different patterns between the gutta-percha brands. CONCLUSIONS Gutta-percha designed for thermoplastic application shrinks quickly and extensively upon cooling.

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Shrinkage of Backfill Gutta-percha upon Cooling

Runnig title: Shrinkage of three different regular backfill Gutta-percha upon cooling

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Key words: Gutta-percha, shrinkage, temperature

Introduction: The temperature and related shrinking kinetics of gutta-percha injected from heat guns are not known and were investigated. **Methods:** Temperatures of 3 different backfill gutta-percha brands extruded from 3 commercially available heat guns set to 200°C were studied. To validate the results, temperature development of one gutta-percha brand injected from a heat gun during a simulated backfilling procedure was assessed in single-rooted human teeth containing thermocouples in a water bath of 37°C. These values were compared to the counterparts obtained in a table-top testing device for shrinkage at an ambient temperature of 37°C. Using this device, linear shrinkage upon cooling was assessed for all 3 gutta-percha brands under investigation. Results were compared by parametric statistics, alpha = .05. **Results:** Temperatures of extruded gutta-percha differed significantly ($P < .05$) between heat guns and gutta-percha brands. Mean temperatures ranging between 57.6 ± 4.5°C and 103.9 ± 7.8°C could be observed with different combinations. The temperature of extruded gutta-percha in table-top experiments equaled that observed in the root canals. However, cooling of gutta-percha was ($P < .05$) faster in the table-top measuring device compared to the root canal environment. Within the controlled temperature drop from 75°C to 37°C, total shrinkage differed significantly ($P < .05$) between the 3 gutta-percha brands under investigation, and ranged between 0.96 ± 0.20% and 2.31 ± 0.26% after 10 min ($P < .05$). Shrinking kinetics showed different patterns between the gutta-percha brands. **Conclusions:** Gutta-percha designed for thermoplastic application shrinks quickly and extensively upon cooling.

The hermetic seal of the canal space continues to be a treatment goal in endodontic clinical practice (1). The main material to achieve this seal is still gutta-percha, a composite consisting of zinc oxide and radiopacifiers in a polyisoprene matrix (2, 3). Gutta-percha has some advantages over other dental materials in that it has a melting interval, i.e. a temperature range in which it becomes moldable, and can thus be mechanically compacted (4). This thermoplasticity enables clinicians to heat gutta-pecha and then compact it into canal irregularities. However, it is not clear whether root-filling techniques using heated gutta-percha are superior in terms of their sealing properties compared to counterparts employing cold cones of the same core material (5). Both techniques rely on sealers to fill gaps between the gutta-percha and the root canal wall. The advantage of moldability of heated gutta-percha is counteracted by the fact that gutta-percha shrinks considerably upon cooling (6-9). Shrinkage of heated gutta-percha has been studied in dilatometers (6-8) and aluminum cylinders in combination with a distance sensor (9). However, these methods required controlled stable temperatures of the specimen for measurement, and could thus not elucidate shrinkage of gutta-percha upon cooling in real time. Moreover, the temperature at which the heated gutta-percha reaches the canal using current injection devices, which are based on older and better documented heat guns (10, 11), is not known.

It was the goal of the present study to assess shrinkage of gutta-percha used for the backfilling procedure under clinically relevant conditions. Specifically, the following null hypotheses were tested:

- The type of heat gun has no influence on the temperature of the gutta-percha that is ejected;
- The brand of regular-flow gutta-percha pellets has no influence on ejection temperature;
- There is neither a difference in the initial temperature nor the time that gutta-percha requires to cool to body temperature between root canals of teeth immersed in a water bath and table-top conditions in a room heated to 37°C;

- There is no difference in linear shrinkage between the different brands of gutta-percha under investigation.

Materials and Methods

Temperature of Gutta-percha Extruded from Heat Guns

Three commercially available endodontic heat guns, which can be loaded with non-proprietary gutta-percha pellets, were used for this experiment: Obutura II and III (SybronEndo Corporation, West Collins, Orange, CA), and SuperEndo-Beta (B&L BioTech, Alexandria, VA). The heat guns were equipped with 25-gauge delivery needles. A thermocouple (Z2-T-2M, Labfacility, Hanau, Germany) was fixed to the tip of each needle using flowable composite (Filtek Supreme XTE; 3M ESPE, St. Paul, MN), which was light cured (Bluephase G2 LED, Ivoclar Vivadent, Schaan, Liechtenstein). Thermocouples were connected to a data logger (Agilent 34970, Agilent, Santa Clara, CA) running proprietary software (Agilent BenchLink). Accuracy of temperature measurements was verified by comparing results from the thermocouples submerged in ice water and tap water heated to 37°C and 80°C with calibrated thermometer readings.

The experiments were performed with 3 different brands of gutta-percha pellets: Obtura Regular Flow (Spartan, Fenton, MO, Lot number: 612P1007), B&L Regular (B&L BioTech, Lot number: 2002Z), and E&Q Gutta-Percha Bars (Meta Biomed, Horsham, PA, Lot number: GE12111374). The measurement was started and the endodontic heat gun was turned on and set to 200°C. After the temperatures on the delivery needle had reached a steady state, warm gutta-percha was extruded, first into a cotton gauge, and then for 10 sec directly onto a second thermocouple, which was held in close proximity (1 mm) to the tip of the delivery needle. This procedure was performed 6 times per combination of gutta-percha and heat gun (54 experiments in total). The maximum temperature that was recorded during each experiment was used for statistical comparison. The device was turned off and cooled down between experiments.

Cooling of Gutta-percha in Human Teeth and in Table-top Experiments

For this experiment, the Obtura II gun was used, equipped with Obtura Regular Flow gutta-percha (Spartan). A total of 8 single-rooted premolars from the department's collection of extracted teeth were used for this study. Endodontic access cavities were prepared using diamond burs (Dentsply Maillefer, Ballaigues, Switzerland). The canal orifices were enlarged using Gates Glidden drills (nos. 4 – 1; Dentsply Maillefer). Determination of the individual working lengths was established visually by inserting a Size 10 K-file (Dentsply Maillefer) until the tip of the file was visible at the foramen. Canal preparations were performed using ProTaper instruments (S1 – F2; Dentsply Maillefer) and ProFile .04 instruments (Dentsply Maillefer) to size 40 for apical enlargement. The apices were shortened by 1 – 2 mm with a diamond bur to create a plateau. The canals were then opened from the apex using Gates Glidden drills nos. 1 – 6. A thermocouple (Z2-T-2M, Labfacility) with a tip diameter of 1.2 mm was inserted from the apex reaching 4 mm into the canals. The position of the thermocouple was checked under a table microscope with an integrated light source (Zeiss, Oberkochen, Germany). After application of a dentin bonding system (Syntac Classic, Ivoclar Vivadent), the thermocouple was fixed with flowable composite (Filtek Supreme XTE; 3M ESPE), which was light cured (Bluephase G2 LED, Ivoclar Vivadent). The outer root surfaces were sealed with nail varnish. To ensure that the heated delivery needle did not touch the intracanal thermocouple during measurement, the distance to the thermocouple was measured by introducing a size 25 K-file into the canal until it met hard resistance. From this recorded distance 1 mm was subtracted and marked with a rubber stop on the delivery needle. Teeth were submerged to the cementoenamel junction in a pre-heated water bath (M3, Lauda, Lauda-Königshofen, Germany) set to 37°C. The temperature of the water bath was measured by a thermocouple submerged in the water. After the intracanal temperature had reached the temperature of the water in the bath, the delivery needle was introduced into the canal to the predetermined working length and gutta-percha was extruded into the canal to simulate a backfilling procedure. Sealer was omitted to prevent insulation of the thermocouple from the gutta-percha temperature. The delivery needle was withdrawn from the tooth as soon as the gutta-percha reached the canal orifice. Measurement was continued until the intracanal temperature reached the temperature of the water bath.

To assess whether the heat drop in gutta-percha was comparable between the situation in situ and in the testing device for shrinkage (see below), the heat drop within the specimens in the device was assessed using the thermocouples described above, which were placed into the middle of the gutta-percha specimens. A second thermocouple was positioned 1 cm from the specimen to monitor ambient temperature. These and the following experiments on shrinkage were performed in a room heated to body temperature (37°C) using an electrical heating ventilator. All these experiments were performed 8 times.

Linear Shrinkage Measurements of Gutta-percha

Linear shrinkage was measured using a custom-made, calibrated testing device, described in detail elsewhere (12). In brief, the measurement apparatus consisted of a stable metal frame, upon which a thin glass platelet with a perpendicular diaphragm was loosely placed. The edge of the diaphragm extended into a recess in the infrared measuring sensor (Fig. 1). This system has an accuracy of 100 nm and a sampling frequency of 5 Hz (13). Slices were cut from the 3 commercially available gutta-percha pellet brands described above. These cylindrical gutta-percha specimens (diameter: 3 mm, height 3 mm) were placed on the glass platelet. On top of the gutta-percha specimen a copper platelet was placed. Using a modified soldering rod set to 85°C, the copper platelet was heated until the temperature of the gutta-percha sample reached 75°C. A thermally conductive paste (Rüeger, Crissier, Switzerland) was placed on top of the copper platelet to enhance heat conduction between the soldering rod and the platelet. During the heating of the gutta-percha, the sample was vertically compressed to a height of 1.7 mm. Subsequently, the heat inductor was removed from the copper platelet and the measurement was immediately started and continued for 10 min. For the linear shrinkage experiments, thermocouples were removed to not falsify measurements. To monitor temperature change in the specimens, measurements were repeated with the thermocouple contained in the gutta-percha. As a negative control for the shrinkage experiments, zirconia cylinders with a diameter of 3 mm and a thickness of 1.7 mm were attached to the measuring device with a flowable resin (Filtek Supreme XTE; 3M ESPE), and heated for 5 min using the soldering rod at 85°C. This was the time required for the specimens to reach 75°C, as was verified by thermocouples attached to their surface.

Data Presentation and Analysis

Data are presented as means and standard deviations. Parametric statistics were employed: Student's t-test for individual comparisons, two-way ANOVA to assess whether the type of heat gun and the brand of gutta-percha had a significant impact on ejection temperature, one-way ANOVA and Tukey's HSD test for multiple comparisons of independent data sets, and rANOVA for repeated measurements. The alpha-type error was set at 5% ($P < .05$).

Results

Three different heat guns were tested initially for the temperature they induced in the gutta-percha brands under investigation. Temperatures differed between the heat guns (Table 1). The 2 Obtura guns extruded the gutta-percha at similar temperatures, while the SuperEndo-Beta gun extruded significantly ($P < .05$) hotter material. The statistical analysis revealed that not only the type of gun, but also the brand of regular-flow backfilling gutta-percha significantly ($P < .05$) affected the temperature of the extruded material. With all 3 guns under investigation, the E&Q gutta-percha was significantly ($P < .05$) hotter than the Obtura or B&L material.

To gain an idea whether temperatures of heated gutta-percha in a human root canal and their development over time could be simulated in table-top experiments, temperature and cooling time were compared using one material (Obtura Regular Flow gutta-percha) and one heat gun (Obtura II). The temperature of extruded Gutta-percha from that gun was 61 ± 2 °C (Table 1). This temperature was identical to that of the thermoplasticized gutta-percha reaching the thermocouple in the root canals of the teeth during the simulated backfilling procedure, 61 ± 2°C. In the root canals, the gutta-percha reached body temperature in 85 ± 26 sec. This temperature drop from 61°C to 37°C in the testing device for linear shrinkage took 60 ± 12 sec ($P < .05$).

To compare linear shrinkage between the 3 gutta-percha brands under investigation, a starting temperature of 75°C was chosen, as this temperature reflected the average between all the gutta-percha brands and guns under investigation (Table 1). The mean linear shrinkage differed significantly ($P < .05$) between the 3 gutta-percha brands (Table 2). In addition, shrinking kinetics varied between products (Fig. 2). When the B&L and the E&Q materials reached ambient temperature (37°C), shrinkage slowed down considerably, yet continued at a slower pace. These materials still shrank significantly ($P < .05$) between 5 and 10 min after removing the heat source. In contrast, Obtura gutta-percha continued to shrink fast after ambient temperature was reached, and then plateaud after 5 min. There was no significant difference in Obtura linear dimensions between 5 and 10 min ($P > .05$).

Discussion

All the null hypotheses of the current study were rejected. In other words:

- The type of heat gun did influence the temperature of the gutta-percha that is ejected;
- The brands of gutta-percha pellets differed in their ejection temperature;

- The cooling times differed from the situation in the tooth compared to the table-top set-up;
- Linear shrinkage differed between the different brands of gutta-percha under investigation.

The third point can be seen as a limitation of the current study. The slower cooling of gutta-percha in root canals compared to the laboratory environment presented in this communication can be explained by the insulating effect of dentin (14). However, cooling time merely differed by 20%, and was thus still much closer to clinical reality compared to the experiments on gutta-percha shrinkage that have been reported in the literature (6-9). One study (15) assessed real-time shrinkage of different gutta-percha filling techniques in simulated glass root canals qualitatively, but not quantitatively. Consequently, the current study would be the first to measure intracanal temperature evolvement of gutta-percha injected from a heat gun and the concurrent shrinkage. One older study assessed canal wall temperature in a similar set-up using thermocouples (16). These authors used heat pluggers as described in the classical Schilder technique. They found the temperature to rise up to 80°C at the most coronal level of the root canal, which is comparable to the current results. Shrinkage of root filling materials, however, appears to be an underrated topic. This is especially in view of the fact that the configuration factor, i.e. the ratio between bonded and non-bonded surfaces, is extremely high in the root canal (17), and so could be the stresses induced by dimensional change of a root filling material. The ISO norm for root canal sealing materials (ISO 6876:2012) merely addresses overall dimensional changes over a period of 30 days (18). Whether sealers can compensate for the fast and massive shrinkage upon cooling of the gutta-percha core material during thermoplastic obturation needs to be addressed in future studies. It would also appear that the classic incremental downpack and incremental backfill technique as proposed by Schilder offers some advantages over more recent continuous downpack and backfill techniques in terms of filling extensions of the canal space (19). This suggests that shrinkage of gutta-percha upon cooling can, at least partly, be compensated by compaction of the material.

A further potentially important observation in the current experiments was that there was an apparent correlation between thermal conductivity of the gutta-percha materials under investigation and their shrinkage upon cooling. It was interesting to note that the E&Q material was extruded considerably hotter than the other materials under investigation. This material also took considerably longer to cool down from 75°C to 37°C in the testing device for shrinkage (Fig. 2). It may be speculated that the differences between the materials under investigation in their shrinking behavior may be attributed to differences in thermal conductivity, material density, and specific heat capacity at constant pressure, or, in other words, thermal diffusivity. Performing these analyses on the gutta-percha brands under investigation was beyond the scope of the current study. The correlation between gutta-percha composition, thermal diffusivity, shrinkage upon cooling, and sealability should be investigated in future studies, so that gutta-percha materials with more desirable properties can be designed.

Acknowledgments

The authors deny any conflict of interest related to this study.

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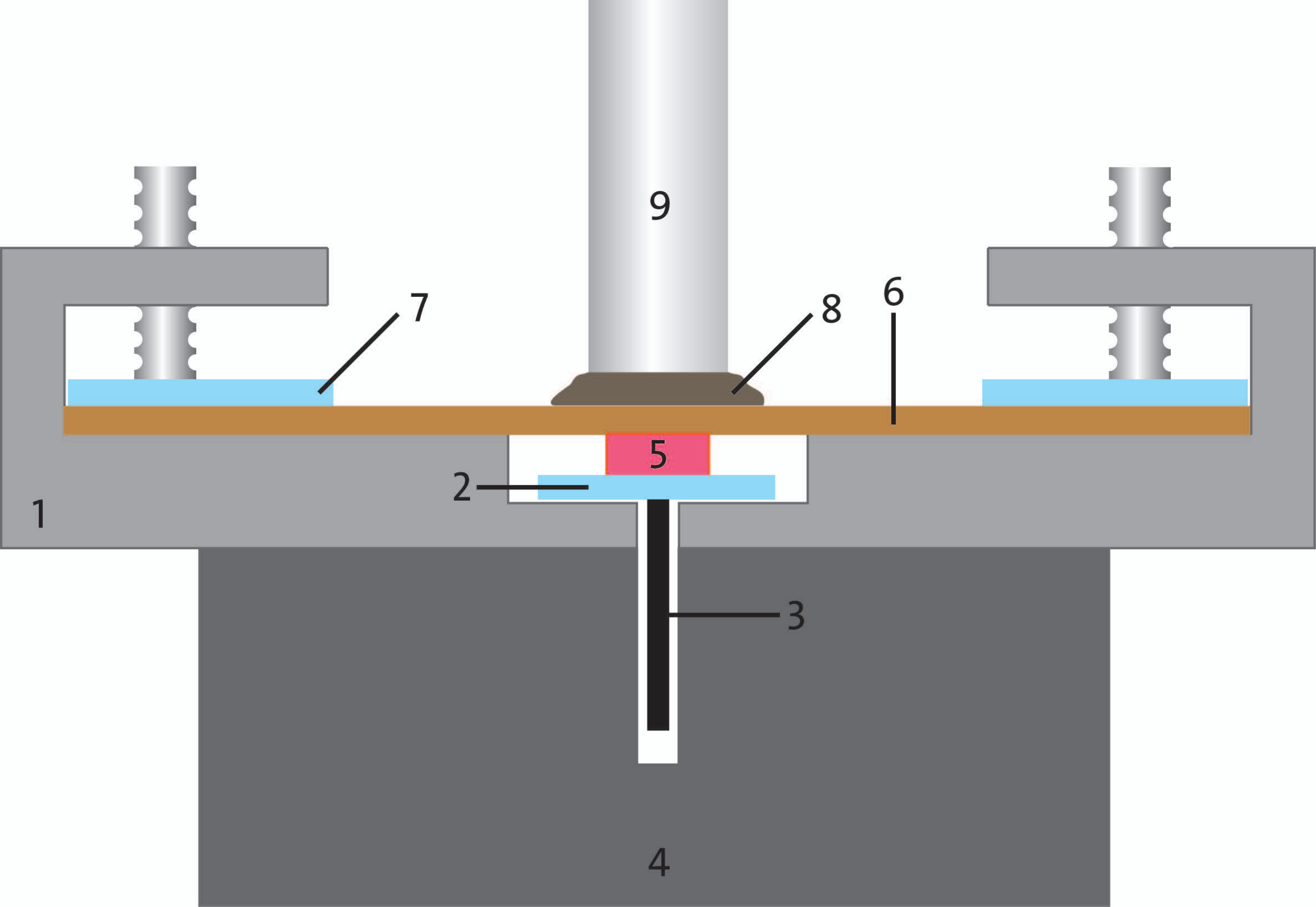
Captions

Figure 1. Schematic drawing of testing device used to measure linear shrinkage of heated gutta-percha. 1: metal frame; 2: glass platelet; 3: diaphragm; 4: infrared measuring sensor; 5: gutta-percha specimen; 6: copper plate; 7: glass plate; 8: thermoconductive paste; 9: soldering rod.

Figure 2. Linear dimensional change (in %) of the 3 gutta-percha brands under investigation when these were cooled from 75°C to 37°C (ambient temperature). Diamonds and dashed lines indicate the mean time when ambient temperature was reached and thus highlight the difference in shrinking kinetics of the materials under investigation. Zirconia specimens heated to 75°C were used as negative controls.



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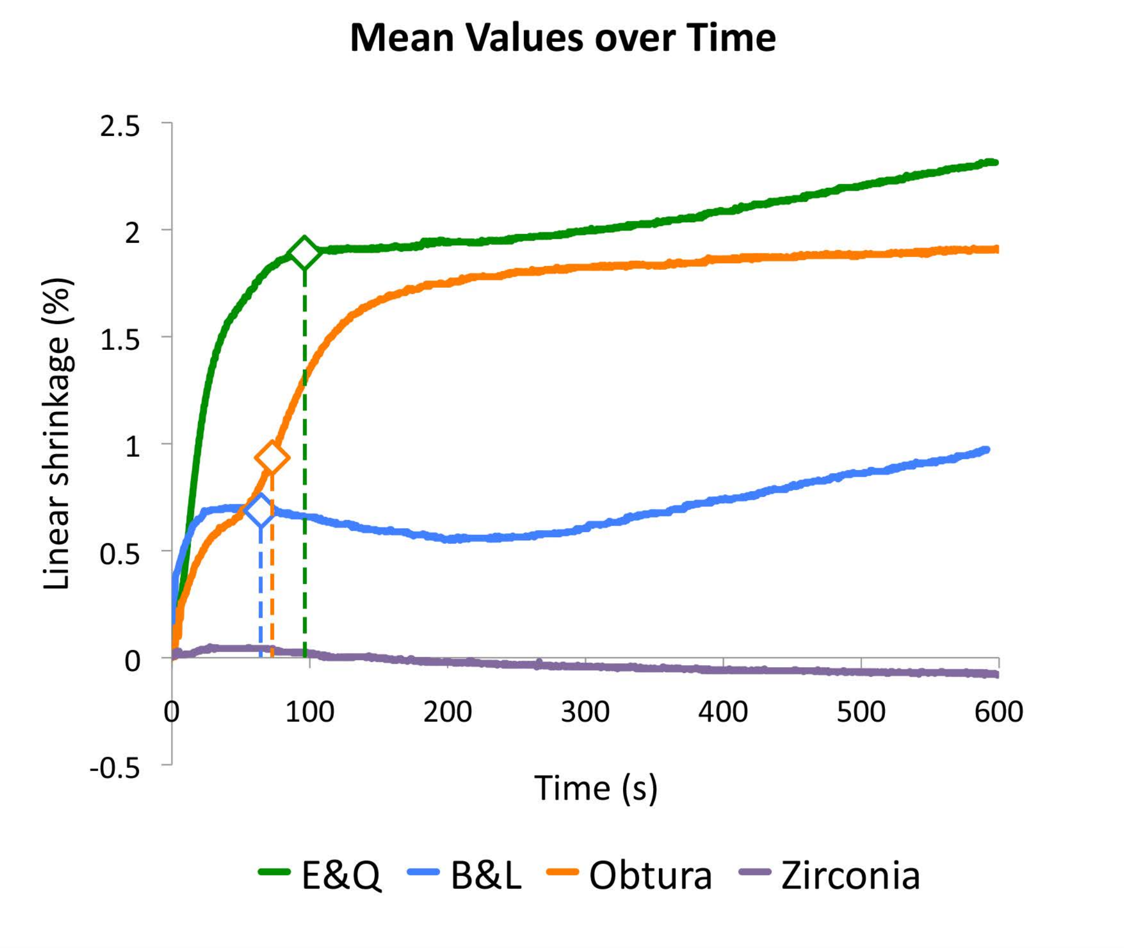

Mean Values over Time
Linear shrinkage (%)
2.5
2
1.5
1
0.5
0
-0.5
0
100
200
300
400
500
600
Time (s)
E&Q
B&L
Obtura
Zirconia

TABLE 1. Temperatures (°C) of Extruded Gutta-percha Brands* from 25-gauge Delivery Needles Attached to Different Gutta-Percha Guns set to 200°C

Gun	Obtura*	B&L*	E&Q*
Obtura II	$61.4 \pm 4.1^{A,B}$	57.6 ± 4.5^{A}	83.4 ± 11.0^{C}
Obtura III	$62.3 \pm 4.6^{A,B}$	$63.4 \pm 3.0^{A,B}$	84.3 ± 10.4^{C}
SuperEndo-Beta	76.9 ± 8.4^{C}	$72.4 \pm 6.4^{B,C}$	103.9 ± 7.8^{D}

All gutta-percha products were of the "regular flow" type. Values indicate means ± standard deviation of 6 separate measurements. Data sets sharing a superscript letter did not differ significantly from each other (one-way ANOVA, Tukey's HSD, $P < .05$)